HARVEY ENGINEERING LABORATORIES for Research & Development
DIVISION OF HARVEY ALUMINUM
TORRANCE, CALIFORNIA

HA NO. 2225 PAGE Title

HA-2225

Progress Report No. 6

RESEARCH PROGRAM TO DEVELOP A TECHNOLOGY IMPROVEMENT PROGRAM FOR CLOSED DIE FORGING

Contract Number NAS8-20093
Control Nr. DCN 1-5-30-12531(1F)

February 1966

For

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

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Activities During Month of January 1966

The activities during this period may be briefly summarized as:

(1) Additional forging tests of 7075 on flat dies.

(2) Preliminary tests of the cupping dies.

(3) Modification of cupping dies.

Flat Die Forging

Continued upset forging on flat dies was aimed at refining of techniques and accumulation of additional data. As in the previous tests, the forging was done on a 500-ton hydraulic press, measuring the thickness of the forged piece and the pressure in the hydraulic system to determine the forging pressure on the piece. In previous tests the hydraulic system was throttled to obtain varying total loads, causing thickness variations in the piece. In these tests full hydraulic pressures were used and the press run against stops to control thickness, or the reversing limit switches were set to control thickness. In both cases, the actual forging load was determined from a time-pressure curve recorded for each forging and the loads calculated from the area of the piece and ram area of the press.

In these tests the reversal of the press provided the best means of determining the effective forging load. This can be seen from the typical time-pressure curves sketched in Figure 1. These were traced from those on the recorder chart and are sufficiently accurate for illustrative purposes. Curve A is representative of the full press load being exerted on the piece, and hence the maximum pressure indicated at point (4) is the effective pressure applied to the forging. Point (1) on this curve corresponds to zero pressure while point (2) indicates the initial pressure rise as the dies contact the piece and deformation begins. The pressure then increases slowly as deformation proceeds and at point (3) the pressure builds up and deformation continues at a rate determined by the pump capacity reaching maximum pressure and final size at point (4). In this case, there is no difficulty in determining the effective forging pressure; it corresponds to the maximum pressure reached in the system.

When the press is run against stops, the same kind of curve is obtained as indicated in Curve B but if it is assumed that point (3) represents the press hitting the stops and that further metal deformation is negligible, this point may be taken as the effective hydraulic pressure in the forging. The point is readily determined since the pressure in the system builds up from here at a constant rate determined by the pump capacity. These pressures may, however, be low since a small amount of deformation will take place as the stops pick up the load and are compressed. This deformation will be small, however, and of more significance in thin compared to thick pieces.

In contrast to using the stops, reversing the press at a given thickness gives curves of C and D types where, again, the maximum indicated pressure determines the load on the piece. In these curves, points (1) and (2) again correspond to the zero and the initial pressure rise on contact, while point (3) denotes the maximum effective hydraulic pressure. Curve C represents a high pressure and, consequently, a thin forged biscuit; while Curve D represents a low effective pressure and a thicker forged biscuit. Data obtained from these curves is considered more accurate and is in line with previous tests.

The data collected are summarized in Tables 1, 2, and 3 and curves plotted are shown in Figures 2 and 3. In these tests, three or four samples were forged for each thickness range and an attempt was made to get data for a range of thicknesses. Cooling of the dies in the press was, however, too rapid to cover as large a range as desired, particularly for the higher temperatures.

Tables 1 and 2 give the data for tests 13 and 14 in which the press was run against stops. In these the die temperatures were approximately 700°F. and higher. Table 3 gives the data for test 15 in which the press was reversed at definite thicknesses. This test covered the full temperature range of 800 to 440°F, and a total of fifty-four samples were forged. The dies were also re-heated in the press in this test, as a means of obtaining more information for the higher temperatures. Reheating however seemed to disturb the die surface and required forging of several samples before producing consistent results.

The data from these tests and that previously obtained were plotted for 50°F. ranges, first as tons per square inch of forged area forging force plotted against thickness, and second as tons per square inch of forged area per inch of thickness also plotted against thickness. In each range the scatter of the data was quite large and gave considerable overlap; and, it is quite clear that many more samples would have to be forged in each condition to obtain meaningful averages. However, the lower values of forging force have the most significance since they indicate the limiting values obtainable while the scatter to the higher values suggest variations due to lubricant deficiency arising from improper or incomplete application, and to variations in surface treatment of the samples or similar factors.

In many instances, as can be seen from scanning the tables of data, the first samples in a group tend to give the highest forging force at the highest temperature and greatest thickness while the last give the lowest of all of these values. This suggests that a conditioning of the die surface takes place as a result of forging successive samples, giving the best results only after a number of samples have been forged. This effect has been often noted in commercial forging and is believed due to improvement of the die surfaces by smoothing out irregularities and working the lubricant into the surface.

The curves shown in Figures 2 and 3 therefore represent the lowest forging force obtained for the thickness. They are assembled on a single chart to show the differences due to die temperature. In Figure 2, forging force per square inch of forged area is plotted against thickness. These suggest minimum thickness has been approached for the 350 to 400°F. and 400 to 450°F die temperature ranges but not at the higher temperatures. They also give a measure of the significant differences in forging force required as die temperature increases. For example, to get .200-inch biscuit thickness a force of about 14 tons per square inch was required with a die temperature of 400 to 450°F, while a die temperature of 700 to 750°F only required about 7.5 tons per square inch. The curves also indicate that lower thicknesses could not be obtained under the test conditions at die temperature below 400°F.

However, it must be remembered that all samples were forged from approximately the same size of slug (2" diameter by 1.5" long) and that the thickness and forged area are interdependent since the volume of the piece is constant. A plot of this relationship si shown in Figure 4. The curve is hyperbolic in form and suggests that the forging force vs thickness should have a similar shape. Dividing the forging force per unit area by thickness gives the forging force per inch of thickness and this plotted against thickness produces curves of the same general shape as the surface thickness relationship shown in Figure 3. These, like the curves of Figure 2, represent the minimum values of forging force for 50° die temperature intervals. These curves, while of the same order of reliability as those of Figure 2 (since they are based on the same data), give a more complete picture of the forging force - thickness - die temperature relationship. They emphasize the steepness of the forging force gradient as the thickness is decreased below .200-inch and also emphasize the influence of die temperature. It is apparent that (for the conditions used in this work) thicknesses in the range of .100-inch can only be approached at the higher die temperatures of 700°F and above, and that the forging force required for a given thickness is significantly reduced as the die temperature is increased.

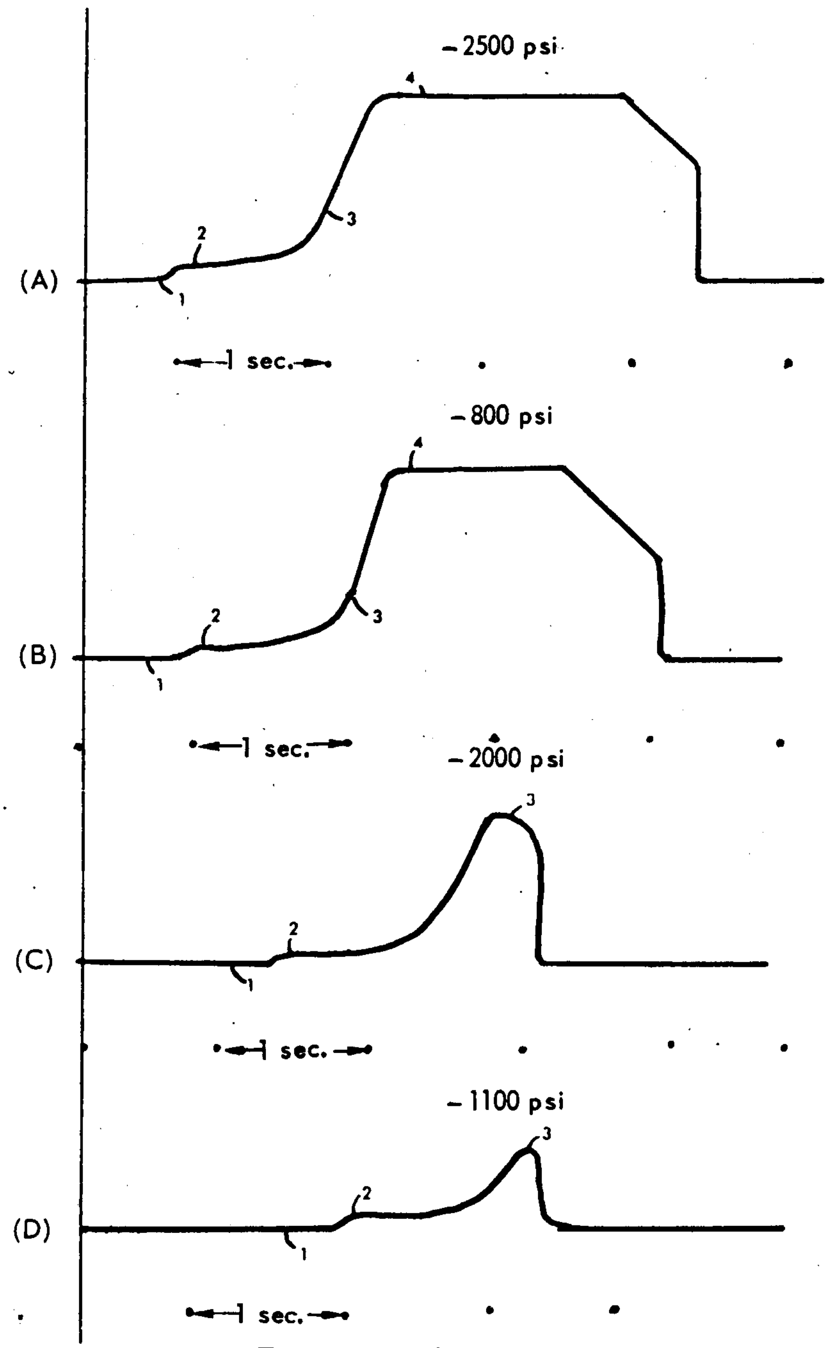

Figure 1. Hydraulic Pressure Curves

Legend:

Typical traces of Pressure-Time curves

(A) Full pressure applied to forging

(B) Press run to stops

(C) &(D) Press reversed by pre-set limit switches

Ordinate pressure

Absissa - Time in Seconds

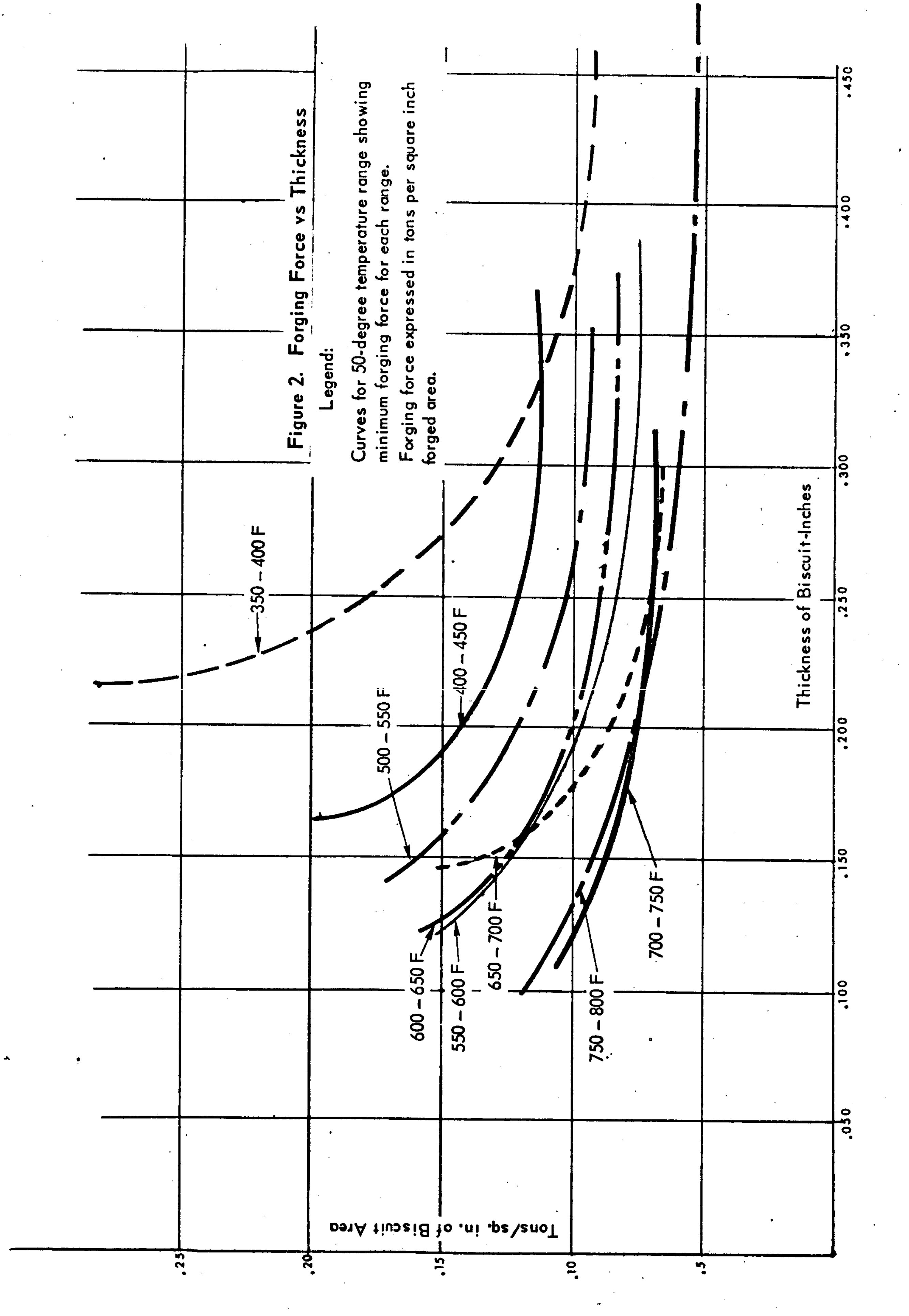

Figure 2. Forging Force vs Thickness

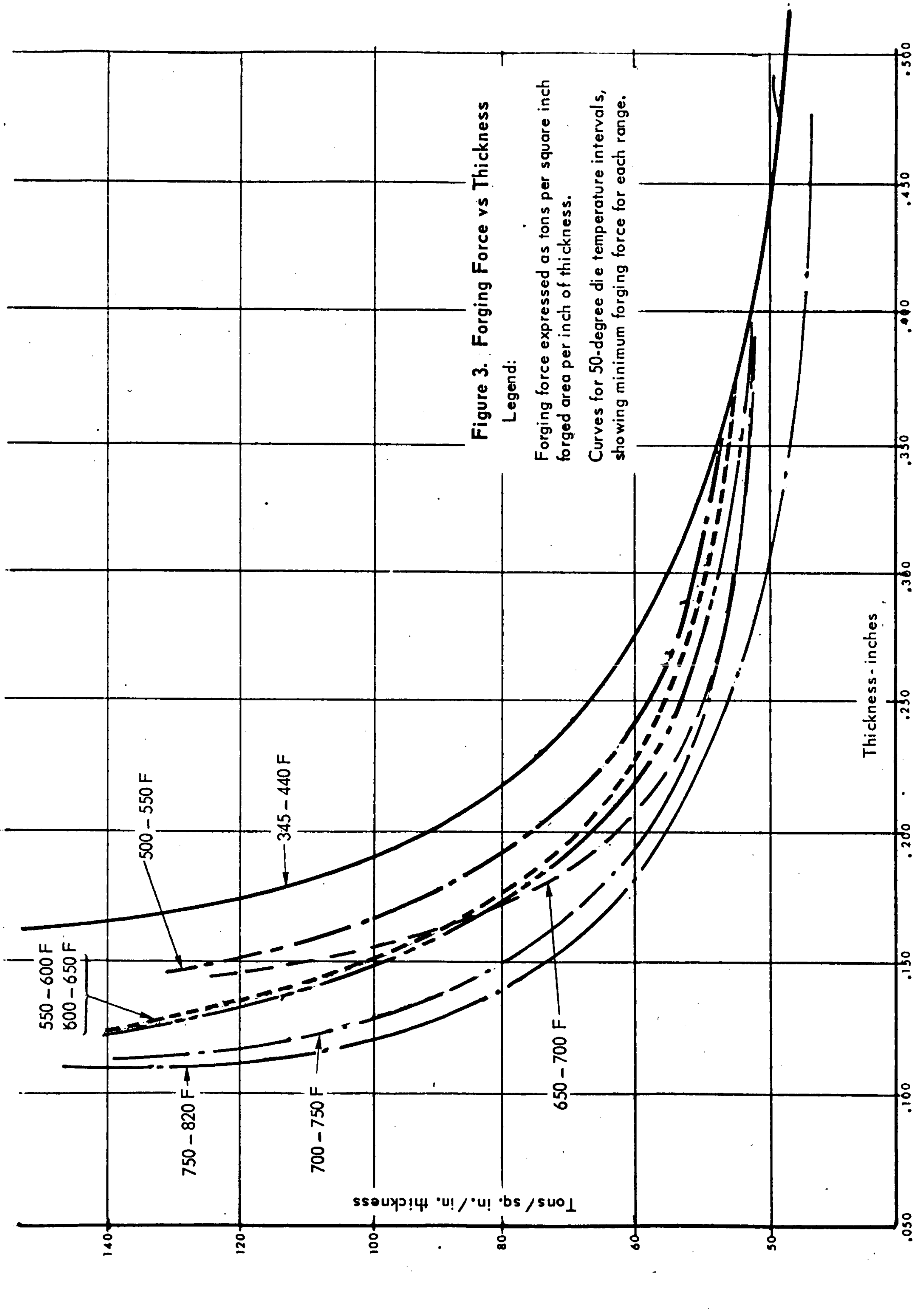

Figure 3. Forging Force vs Thickness

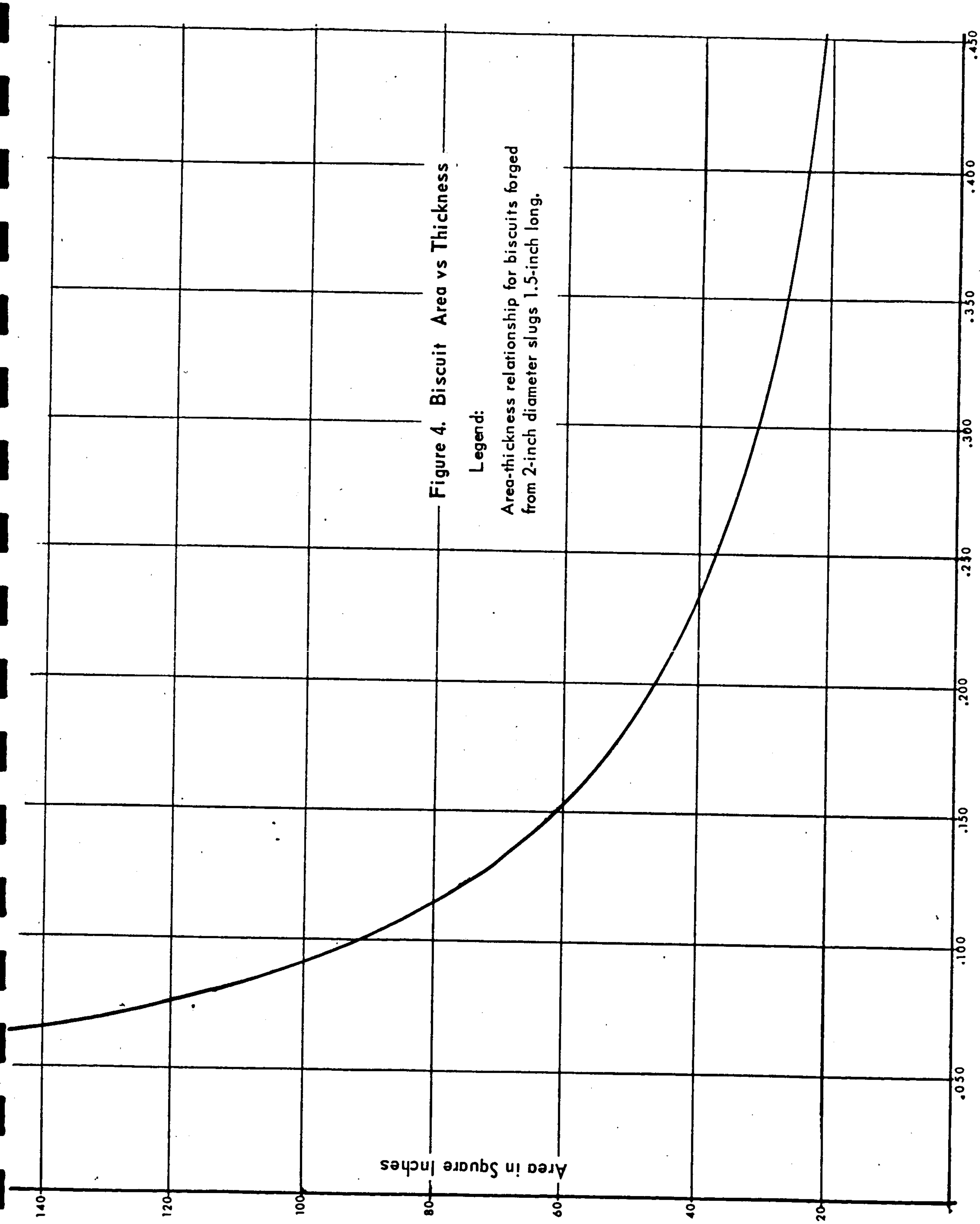

Figure 4. Biscuit Area vs Thickness

Table 1

DATA FROM TEST 13

Stock Size: 2-inch diameter, 1.42-inch long
Stock Temperature: 800°F
Press run against stops

Sample No.	Die Temperature (Degrees F)	Pressure (psi)	Biscuit Thickness (in.)	Area Sq.In.	Forging Force	
					Tons per Sq.In.	Tons per sq.in./in. Thickness
1	825	600	.359	12.4	10.9	30
2	795	500	.355	12.6	9.0	25
3	785	450	.352	12.7	8.0	23
4	775	400	.350	13.3	6.8	19.5
5	760	500	.296	15.1	7.5	25
6	750	500	.295	15.1	7.5	25
7	745	500	.296	15.1	7.5	25
8	735	500	.296	15.1	7.5	25
9	720	650	.246	18.1	8.1	33
10	710	600	.246	18.1	7.5	30
11	705	650	.246	18.1	8.1	33
12	700	600	.246	18.1	7.5	30
13	695	900	.205	21.8	9.3	45
14	690	850	.204	21.8	8.8	43

Table 2

DATA FROM TEST 14

Stock size: 2-inch diameter by 1.42-inch long
Stock Temperature: 800°F
Press run against stops

Sample No.	Die Temperature (Degrees F)	Pressure (psi)	Biscuit Dimensions Thickness (in.)	Area (sq.in.)	Forging Force Tons per sq.in.	Tons per sq.in/in.
1	778	2500*	.136	32.8	17.2	127
2	777	2500*	.126	35.4	16.0	127
3	772	2500*	.121	36.9	15.3	126
4	766	2500*	.116	38.5	14.7	127
5	759	1300	.133	33.5	8.7	65
6	754	1500	.134	33.3	10.2	76
7	749	1500	.131	34.1	9.9	76
8	737	1200	.159	28.1	9.6	60
9	733	1200	.161	27.7	9.8	61
10	728	1200	.161	27.7	9.8	61
11	724	800	.200	22.3	8.1	41
12	720	800	.198	22.5	8.0	41
13	710	800	.200	22.3	8.1	41
14	703	600	.245	18.2	7.4	30
15	700	600	.245	18.2	7.4	30
16	695	600	.245	18.2	7.4	30

* No Stops. Full load of press used for these.

Table 3

DATA FROM TEST 14

Stock Size: 2-inch diameter by 1.5-inch long
Stock Temperature: 800°F
Press limited by reversal

Sample No.	Die Temperature (degrees F)	Pressure (psi)	Average Biscuit Dimensions: Thickness (in.)	Average Biscuit Dimensions: Area (sq.in.)	Forging Force: Tons per sq.in. area	Forging Force: Tons per sq.in./in. thickness
1	805	2500*	.148	31.8	17.8	120
2	800	2500*	.138	34.1	16.6	120
3	790	2500*	.137	34.4	16.4	120
4	780	2330	.163	28.9	18.2	111
5	780	2100	.154	30.6	15.5	101
6	775	2160	.153	30.8	15.8	103
7	875**	2500*	-***	-	-	-
8	805	2500	.181	26.0	21.7	120
9	790	2500	.159	29.6	19.1	120
10	780	2500	.150	31.4	17.6	117
11	775	2150	.161	29.3	16.6	103
12	770	2000	.162	29.1	15.5	96
13	760	2000	.158	29.8	15.2	96
14	755	1200	.197	23.9	11.3	57
15	750	1250	.201	23.4	12.1	60
16	745	1230	.194	24.3	11.4	58
17	725	2500*	.138	34.1	16.6	120
18	720	2500*	.138	34.1	16.6	120

Table 3 - Continued

Sample No.	Die Temperature (degrees F)	Pressure (psi)	Average Biscuit Dimensions Thickness (in.)	Average Biscuit Dimensions Area (sq.in.)	Forging Force Tons per sq.in. area	Forging Force Tons per sq.in./in. thickness
19	715	2500*	.139	33.9	16.7	120
20	710	2510	.148	31.8	17.8	120
21	705	2520	.144	32.7	18.7	130
22	705	2510	.147	32.1	17.7	120
23	700	2000	.158	29.8	15.2	96
24	690	1900	.153	30.8	13.9	91
25	690	1930	.155	30.4	14.4	93
26	690	2100	.159	29.6	16.0	101
27	690	2080	.153	30.8	15.3	100
28	685	2180	.154	30.6	16.1	105
29	605	2500*	.142	33.2	17.0	120
30	605	2500*	.146	32.3	17.5	120
31	605	2500*	.153	30.8	18.3	120
32	605	2500*	.153	30.8	18.3	120
33	605	2390	.162	29.1	18.6	115
34	600	2400	.166	28.4	19.1	115
35	600	2400	.163	28.9	18.8	115
36	595	2330	.166	28.4	18.5	111
37	595	2400	.172	27.4	19.8	115
38	595	2350	.170	27.7	19.2	113
39	590	1020	.224	21.0	11.0	49

Table 3 - Continued

Sample No.	Die Temperature (degrees F)	Pressure (psi)	Average Biscuit Dimensions Thickness (in.)	Average Biscuit Dimensions Area (sq.in)	Forging Force Tons per sq.in. area	Forging Force Tons per sq.in./in. thickness
40	590	1100	.223	21.0	11.0	49
41	590	1050	.224	21.0	11.0	49
42	580	1000	.230	20.5	11.0	48
43	580	1000	.234	20.1	11.2	48
44	580	1000	.237	19.9	11.4	48
45	440	2500*	.165	28.6	19.8	120
46	440	2400	.177	26.6	20.4	115
47	440	2400	.175	26.7	20.2	115
48	440	2400	.175	26.9	20.6	118
49	440	2320	.183	25.7	20.4	111
50	440	2290	.185	25.5	20.3	110
51	440	2400	.187	25.2	20.2	108
52	440	1230	.238	19.8	14.0	59
53	440	1150	.240	19.6	13.3	55
54	440	1150	.241	19.6	13.3	55

*Full load of press applied
**Dies reheated in press at this point
***This sample cracked.

Cupping Die Tests

These tests were conducted to try out the cupping die, to determine if any changes were required, and as a means of establishing the technique necessary in such tests. Forging pressure and cup dimension were measured for several die temperatures. However, the main purpose was to check out the dies. The following factors needing revision were found:

1. The initial design of these dies did not provide for placement of thermocouples to follow die temperature. The need for these was recognized, but their placement was deferred until tests of the dies so that they could be positioned in a manner which would not interfere with the operation. The tests indicated that thermocouples could be placed in the punch about 1/2-inch beneath the working face and in the wall of the insert. It appears that only these two thermocouples will be required and that the die parts can be safely altered to take them without seriously weakening the die.

2. Allowances for thermal expansion of the slugs were found to be insufficient and the slugs did not completely enter the die insert. Recalculation of the slug size and die parts with temperature for the various combinations of die temperature and stock temperature indicate that the aluminum alloy 7075 slugs should be 2.470-inch diameter, the maraging steel and the titanium should be 2.475-inch diameter in order to enter the insert under all conditions to be used.

3. The position of the insert in the die holder was approximately 1/4-inch below the top of the holder. This is due to the differential in expansion between the insert at 600 to 800^{o}F and the holder at about 300 to 400^{o}F. A 1/4-inch plate will be fastened to the pressure pad to correct for this. This plate will also take care of the Inconel die parts as well.

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4. The plug closure of the die insert did not accurately fit the insert. This will be taken care of by making a new plug closely fitted to the insert.

5. A second insert and plug assembly will be made so that one may be heated while the other is in use.

6. The wall of the cups varied from side to side, indicating the need for closer control of alignment of the die and punch. The construction of the die is such that this will have to be accomplished by location of the pressure pad based on the punch position. This must be taken care of in assembly of the die in the press.

7. Spacers are required for the base of the punch. These are seated on a taper and it is believed that spacers beneath the punches would aid in holding the vertical alignment of the punches.

8. Placement of the slug in the die turned out to be a greater problem than anticipated. With the aluminum alloy and die temperature of 800°F and below the slug can be dropped onto the punch from the top of the die. At the higher die and slug temperatures to be used for titanium and maraging steel this will not be satisfactory. Accordingly, tongs with adjustable prongs which can be set to the required punch and slug diameters were designed. These will allow placement of the slug on top of the punch and center it so that it will enter the insert cavity without contacting the sides.

Revision of the die drawing to take care of the above factors has been completed and machining of the die parts in accord with these changes have been started.

Work Programmed for February

1. Hot die forging tests on titanium and maraging steels.
2. Completion of revisions of the cupping die.
3. Second tryout of cupping dies